COMPARISON OF MAKERSPACE LEARNING OUTCOMES BETWEEN GENDERS, UNIVERSITIES, AND ONLINE COMMUNITIES

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COMPARISON OF MAKERSPACE LEARNING OUTCOMES BETWEEN GENDERS, UNIVERSITIES, AND ONLINE COMMUNITIES

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SUMMARY

Academic makerspaces are places where students can explore, learn, build, and form relationships throughout their education. As the number of academic makerspaces continues to grow rapidly, very little empirical evidence describes students' learning outcomes from their involvement in these spaces. Prior work investigated how university makerspaces are supporting women students as designers, learners, makers, and community members. Through this the Learning through Making Typology was developed showcasing the breadth of women students' learning in the makerspaces. To further understand student learning and how learning outcomes compare across different populations in our makerspaces, interviews were conducted at two universities (Big City U & Comprehensive U). The universities chosen were selected based on their fundamental differences in makerspace & engineering curriculum structure. Using an in-depth phenomenologically based interviewing process we are able to gain insight into the participants' lived experiences in the makerspace. Through a rigorous qualitative data analysis process of over 1000 pages of single-spaced transcriptions we are able to compare student learning across gender and universities. The analyses revealed our makerspaces are no escape from societal and engineering culture, and much of our data was rich in themes of gendered expectations, benevolent sexism, and competition. Throughout these analyses the significance of online learning became apparent for our participants. A model was developed showcasing how students are learning online and how this online learning supplements their in-person making.

CHAPTER 1. INTRODUCTION

1.1 Motivation and Overview

To succeed in an increasingly complex world, modern engineers must have a comprehensive skill set far beyond the technical. The 21st century engineer is a strong communicator, collaborator, and innovator. One way engineering education may prepare students as 21st century engineers is through multi-disciplinary learning opportunities [1, 2]. In response, academic institutions globally have invested into many approaches including in developing makerspaces and fabrication labs for their students. Makerspaces provide an opportunity for students from different backgrounds to collaborate and solve hands-on, real world challenges.

Creating a makerspace requires significant resources, including monetary investments, sufficient space, and thorough planning. Though the number of academic makerspaces are rapidly increasing on college and university campuses [3], little empirical evidence exists for the value they bring to the educational and professional development of students [4, 5], especially for how learning experiences compares across genders and different makerspace communities. We know there are significant barriers to entry for women students [6-8], but it is also clear that makerspace involvement helps develop a variety of skills and competencies [7, 9].

In our previous work, the Learning through Making Typology for students' involvement in the makerspace was developed showcasing how and what women students are learning while engaged in these communities. Our prior work focused on creating a typology of learning to demonstrate how and what women students, in particular, learn in academic makerspaces. This study seeks to further apply this learning typology [7] to compare both women and men’s learning experiences at two different universities, demonstrating the potential of the typology for informing understandings of learning in a variety of contexts and across different social groups. Using the same phenomenologically based interview methodology adapted by Tomko [7], we demonstrate the power of the learning typology for studying experiences in makerspaces across different university communities. More specifically, we compare the experiences of men and women makers, as well as the learning across two different universities characterized by varied degrees of making integrated into their curriculum. By exploring these comparisons, we gain insight into how to develop makerspaces (and engineering curricula) that facilitate deepened student learning and greater inclusivity.

Further, over the past decade, practices related to online learning have become increasingly varied and legitimated. Students are highly adept in using online platforms to find answers to many questions they may have and to solve academic problems [10, 11]. This informal, self-directed practice can facilitate students’ active and experiential learning [12]. These self-directed online learning practices also have important implications for nascent makers. The rise of the maker movement, coupled with this digital transformation, has paralleled rapid growth of online making communities [13]. Online tools and communities advocate learning through making, building, tinkering, playing, and creating [14]. Members’ activities in such communities generally seek to master one’s own making abilities while contributing to shaping the practice for others [15]. While makers learn through these online platforms, this online learning is known to supplement in-person learning and experimentation [15]. Previous examinations of maker communities have focused on student learning within academic makerspaces. But in the digital age, student learning goes far beyond the walls of the makerspace. Online communities extend our local academic making communities connecting our students internationally to makers of all backgrounds and expertise. Through understanding how these online communities are supporting our students we can gain insight into how to effectively incorporate online methods to supplement traditional face to face learning.

1.2 Research Questions

This study is a continuation of prior work that aimed to investigate the breadth of learning and the interaction of competencies for women students in makerspaces. The Learning through Making Typology [7] was created to capture both how and what women students learn from makerspaces. To further investigate student learning, this study seeks to answer the following research questions:

RQ 1: Do design competencies and learning types differ across learning communities with varied degrees of making integrated into the curriculum? How?

RQ 2: Do men and women differ in their accounts of competencies and learning types in an academic makerspace? How?

RQ 3: How are online communities and resources supporting student learning in makerspaces?

To answer the research questions, in-depth phenomenologically based interviews were conducted at two universities. Big City U is a large tech focused public school in the south with an open makerspace. Comprehensive U is a public university in the south with a small engineering program that integrates the makerspace into the curriculum. Through a rigorous data analysis process, each interview was coded using the previously developed Learning through Making Typology as a basis. New codes were added as needed to ensure the data was at saturation. Through a combination of quantitative and qualitative analyses, we are able to expose the similarities and differences in student learning among these populations to answer RQ 1 & 2. Throughout the qualitative data analysis, the prevalence of online learning emerged and a model showcasing how students learn online developed.

1.3 Thesis Organization

The remainder of this thesis is outlined in the following manner. Chapter 2 presents a review of background information on makerspaces and the maker movement, student learning within these spaces and online learning. Chapter 3 describes the qualitative methodology used for this study including details about the interview protocol, data analysis process, and our participants. Chapter 4 presents the findings found over the course of the study and discusses their significance and implications. Chapter 5 presents a conclusion of the results of the study and Chapter 6 outlines the limitations of this study as well as the steps to be taken in future works.

CHAPTER 2. BACKGROUND

No single definition can represent the variety of makerspaces, fab labs, or hackerspaces that exist. In general, makerspaces are places where makers can come together to create, design, and build new projects while sharing ideas, equipment, and knowledge. Makerspaces are non-traditional machine shops focused on rapid prototyping (e.g., 3D printing) and typical manufacturing equipment (e.g., hand tools) [16]. Unlike a lab, which is often limited to a single activity, community, or course, makerspaces are often open spaces for students to work on academic, extracurricular, or personal projects. Makerspaces embody *Learning by Doing* fostering a culture of collaboration, openness, and hands-on learning. Importantly, this definition of makerspaces is based on a Euro-centric narrative of making and is noted as being not wholly inclusive of making (e.g., making may include developing story, fostering relationships, cooking [17]. Herein, this Euro-centric definition of making and makerspaces is studied due to the prevalence of this narrative throughout the United States in mechanical engineering departments and engineering colleges. By one estimate, at the beginning of 2019, 41% of state universities and colleges have (or plan to have) one or more makerspaces [18]. Beyond the United States, many academic institutions and learning environments around the world have committed to the development of makerspace environments due to their perceived educational benefits [5, 19-22]. Between 2006 and 2016, the number of makerspaces increased 14-fold internationally [3].

2.1 Makerspaces, Maker Movement & Maker Culture

The Maker Movement has re-cast making as activities focused on the use of additive manufacturing and digital prototyping technologies. Halverson and Sheridan [23] broadly define the maker movement through “the growing number of people who are engaged in the creative production of artifacts in their daily lives and who find physical and digital forums to share their processes and products with others.” Kelly referred to the maker movement era as a third industrial revolution, asserting that the digital is embodied by the physical in this new matrix for civilization [24]. Melo suggests that the Maker Movement did not invent making, but rather branded it [18]. The Maker Movement consists of three transformative characteristics according to Anderson [25]:

1. people who use digital tools to create new designs for immediate prototype

2. people who are in a cultural environment that fosters collaboration and sharing

3. people who use common design standards

The movement has gained traction in the last fifteen years, catalyzed by the launch of *MAKE:* Magazine in 2005 [26]. The *MAKE:* division and the Maker Movement have become synonymous over time and are leaders of the growing community of makers [26]. The Maker Movement has generated much enthusiasm globally, leading to maker-centric events such as make-a-thons, a National Week of Making under the Obama administration, and the widespread integration of makerspaces within academic institutions and communities [27]. Over time, makers have expanded into their own market developing new products and services. Innovation in manufacturing, engineering, industrial design, hardware technology and education has been fueled by these ingenious makers coupled with innovative technologies such as the Arduino microcontroller and personal 3D printers [26].

While the Maker Movement developed outside of academic institutions, there are many benefits to incorporating elements of the movement into the academic environment. The Maker Movement is rooted in *Learning by Doing*, providing makers with contextualized experiences enabling deeper understanding and bridging theory to application. Piaget argues testing ideas out allows one to compare expectations against reality, which can create conceptual disequilibrium, and in turn lead to conceptual adaptation [28]. Making also creates an opportunity for social engagement centered around a shared experience. This can unite participants of various experience levels together, a situation that often facilitates learning [5, 29, 30].

“Maker culture has become a way to express creative and communal drive,” centered around learning and applying practical skills innovatively [23, 31]. Makerspace communities foster an environment of collaboration, considered one of the essential 21st century skills [32, 33]. Makerspaces provide a safe space for participants to meet and mentor one another and often serve as places of outreach to other communities. These spaces represent an “effort to support ‘bottom-up’ or grassroots student engineering” facilitating extracurricular personal projects and exploring manufacturing techniques [16]. They afford students an opportunity to connect to real world issues and solve meaningful problems. It has been found that students who engage in maker culture activities develop a sense of personal agency, improved self-efficacy and self-esteem, and become members of a greater community [23, 34, 35]. In an educational setting, generally, students enjoy studying and working in the maker culture context, particularly if they work in a team and have freedom to choose their projects [35-42].

In terms of the culture of making, *Make:* Magazine and Maker Movement have been noted of propelling a narrative of making as one that is white, male, and affluent [17]. These broader cultural issues are noted within the makerspaces in higher education through access issues, gender disparities, and both implicit and explicit expectations for users who do not fit the local stereotypes of makers.

2.2 Student Learning in Makerspaces

Students engage in building physical models through opportunities in the makerspace. By doing so, the students are able to further engage in the design process helping them to imagine concepts more clearly, determine implicit elements of a design, confirm assumptions and functionality of ideas, and select concepts, all while improving communication among team members [43-51]. Through physical modeling, student design teams are better able to identify problems and recognize unwanted behaviors of their ideas [49, 52, 53]. Low-fidelity prototyping is important throughout engineering design, and thus commonplace in the makerspaces.

This type of hands-on, idea into the physical is the core of constructionism, which extends the theory of constructivism focusing on how knowledge is constructed in context [54-57]. Constructionism is a theory of learning, where an individual learns through making of external artifacts [57]. The artifact itself functions as an evolving representation of the learner’s thinking and promotes understanding through interpretation – a process that further develops knowledge [57, 58]. Through transforming one’s inner feelings and ideas into a physical artifact that can be analyzed learning happens, while helping to inform the individual, and shape or communicate their ideas [58-60]. Constructionism offers a foundation for learning in the makerspaces, where participants engage in making in all of its forms [61]. Papert [62] asserts there is a connection between the process for learning and content from learning – furthering the need to understand how and what students are learning in the makerspaces.

As of current there is limited empirical data in regard to student learning in makerspaces. Makerspaces are seen as a means to developing 21st century skills, by inspiring participant's creativity, critical problem solving, curiosity, determination, independence and grit [23, 63-66]. Studies investigating the Maker Movement in education specifically fall into three primary categories [23, 67]:

1. understanding makerspaces as learning environments

2. understanding makers as learners

3. understanding making as a designed learning activity

The first category, understanding makerspaces as learning environments, is of particular interest for this work. Shively argued living and learning community makerspaces are helping students develop professionally and prepare for their careers, while building a community, exploring areas of interest, gaining experience, and experimenting with ideas [68]. Bieraugel and Neill [69] studied academic library spaces and examined student perceptions on how different makerspaces support certain behaviors and learning that forward creativity and innovation. Makerspaces prove very challenging to study, as their experiential, collaborative, self-paced, and interactive nature are not compatible with controlled, quasi-experimental studies [23, 59, 70-72].

To cope with these challenges, in our prior work, Tomko [7] developed and employed a qualitative, interview based approach for studying students' learning in makerspaces. Tomko's work focuses on women students in particular at Big City U. Through the interviews conducted the Learning through Making Typology developed which captures the breadth of student learning in the makerspace [7]. Table 1 shows the six primary categories of the typology. The typology is categorized by modes of learning and products of learning. Modes of learning account for **how** the students are learning. Products of learning account for **what** the students are learning from their experiences in the makerspace. Products of learning is further categorized into cognitive competencies, interpersonal competencies, and intrapersonal competencies. Cognitive competencies refer to the knowledge the students gain, interpersonal competencies are the social skills developed, and intrapersonal competencies are the internal skills and awareness acquired from the activities and social interactions within making and the makerspace.

Table 1: Learning through Making Typology at a Glance

Learning through Making Typology				
		Primary Category	**Sub-Categories**	**Definition**
Modes of Learning		**Learning by Doing**	Failing Struggling Practicing Iterating Exploring	Discussion of learning by doing - learning through experiences as a direct result of one's own actions.
	Interpersonal Competencies	**Learning by Others/ Communicating & Managing**	Observing/ Listening Collaborating Receiving Help or Training Giving Help Leading/ Managing	Discussion of seeing what other people are doing or interacting with other people as a way to beget more understanding of something.
Cognitive Competencies		**Content Knowledge & Skills**	Design Manufacturing & Tools Computational Tools Materials Components	Discussion on the knowledge, skills, and technical jargon acquired in various subject areas.
		Cultural Knowledge & Skills	Access Conventions & Protocols Roles & Structure of Participation Rules of the Community Gendered Experiences	Discussion on navigating a community [in this case the makerspace community] along with the physical space and what the person comes to understand about that community.
Intrapersonal Competencies		**Ingenuity**	Improvisation Opportunism Resourcefulness	Discussion on an informal seeking out solutions or being aware of strategies to use in performing a task.
		Self-Awareness	Confidence Patience Resilience Reflective	Discussion on the motivating factors towards one's attitude along with one's personal attributes/characteristics.

Learning by Doing and Learning through Others comprise the modes of learning. The key distinction between these two categories is that Learning by Doing is a physical activity and Learning through Others is a social activity. Learning by Doing is denoted by the discussion of learning through experiences or hands-on activity. Learning through Others is characterized by a participant discussing learning from someone else, whether it be from interacting with them or simply watching. For example, a participant sitting in the space and observing others' ideas to incorporate into their own making or add to their reservoir of knowledge.

The remaining categories: Content Knowledge, Cultural Knowledge, Ingenuity, and Self-Awareness make up the products of learning. Content Knowledge and Cultural Knowledge constitute the cognitive competencies. Content Knowledge and Skills refers to the participant's understanding or skills associated with an array of topics. This includes, for example, a participant explaining how a tool works. Cultural Knowledge and Skills capture the participant coming to understand the nuances and rules of the community, both explicit and implicit. It is characterized by participants talking about navigating the makerspace community. The intrapersonal competencies are made up of Ingenuity and Self-Awareness. Ingenuity represents a participant informally using innovative means or strategies to find a solution. This is linked to the participant's adaptability to various situations. Self-Awareness is the motivating factors towards one's attitude and personal characteristics. For example, a participant finding confidence through facing their anxieties associated with the makerspace. The interpersonal competencies are communicating and managing, which are included in Learning through Others.

2.3 Online Learning & Digital Maker Communities

Online learning is defined as "learning experiences in synchronous or asynchronous environments using different devices (e.g., mobile phones, laptops, etc.) with internet access. In these environments, students can be anywhere (independent) to learn and interact with instructors and other students" [73]. Online learning is a tool that can make the teaching–learning process more student-centered, more innovative, and more flexible [74].

Research suggests online learning environments support learning outcomes comparable to face-to-face instruction [75-77], though this finding does not yet appear substantiated for online maker communities versus in-person maker communities.

Halverson and Sheridan's broad definition of the maker movement "the growing number of people who are engaged in the creative production of artifacts in their daily lives and who find physical and digital forums to share their processes and products with others" accounts for the "digital" aspect of the maker movement [23]. Given the dramatic increase of technology as a means of social connection, it makes sense that the maker movement has spread online as well. Makers may share their experiences and projects through a variety of platforms such as video-host sites, online forums, or websites curated for makers such as Thingiverse creating online communities which extend making communities—our local academic makerspace communities included—to connect makers to makers around the world.

Digital maker cultures have created collaborative learning communities of many forms. Niemeyer and Gerber found the YouTube making community exhibits a collaborative, participatory learning environment to create new designs where all participants are highly engaged, work together to teach, learn from each other, and collaboratively reach common goals [31]. Platforms such as Thingiverse allow visitors to download publicly available files, reproduce them using local fabrication equipment, and reupload their "remixes" to the site to share with other makers. This creates a community of makers contributing to the development of new designs by iteratively remixing and refining one another's work [13]. Oehlberg, Willett, and Mackay [13] suggest this may also provide an entry point for new makers, who can dissect and build upon other's work to kickstart their own making practice.

CHAPTER 3. METHODOLOGY

To answer the research questions, 34 in-depth phenomenologically based interviews were conducted with a total of 19 participants at two different public U.S. universities, Big City U and Comprehensive U, two schools chosen for their very different approaches to educating engineering students as well as their very different uses of making and makerspaces in engineering education.

Big City U boasts over 30,000 square feet of design-build-play space between just three of its eight makerspaces on campus. One of which being the nation's largest volunteer student-run makerspace. The studio operates thanks to these volunteers serving 3 hours a week in exchange for 24/7 access to the facilities. The Executive Board consists of eight elected student volunteers who work with their Faculty Advisor and school staff members to handle major decisions and keep the space open and functional. There are no restrictions on types of projects, personal projects are as welcome as academic. This open environment enables the makerspaces to be used more freely and integrated into multiple classes. In total, the studio is used in 25 different classes including sophomore and senior design courses.

Comprehensive U's undergraduate engineering experience is based on a philosophy of learning by doing. Comprehensive U offers a much smaller engineering program in comparison to Big City U, enabling supportive mentoring by faculty and a high level of student engagement. Comprehensive U's makerspaces are staffed by paid student workers. An important difference to note is Comprehensive U does not distinguish between the various disciplines of engineering, rather they offer one general engineering degree. Their curriculum is project-based, bringing students into their makerspaces the first semester. While Big City U's makerspace is integrated into their curriculum it is not nearly to the level of Comprehensive U's. At Big City U, for example, a mechanical engineering undergraduate student may only use the space two semesters (sophomore and senior design) whereas Comprehensive U nearly every semester an engineering student is required to use the space to complete academic projects.

3.1 The Participants & Interviewers

The in-depth phenomenologically based interviewing (PBI) process utilized in this study was developed by Seidman based in the phenomenology of Alfred Schutz and the principles of life history interviewing [78, 79]. Two types of PBIs were conducted: a three-series interview and a single targeted interview protocol. Nine students participated in a three-series interview, the original PBI process described by Seidman, with each of the three interviews lasting 90 minutes [80]. Ten students participated in single-targeted interviews adapted from the original PBI process each lasting between 60-90 minutes. Both protocols are centered around understanding the participants lived experience in the makerspace [7, 81].

Big City U employed the modified single targeted interview and Comprehensive U the original three series PBI. The Learning through Making Typology was developed at Big City U, in order to ensure we have a robust data set at Comprehensive U the original three series PBI was utilized. In the three series, the first interview sought to understand the participant's past experiences in learning through making. The second interview focused on understanding the details of these past experiences in the makerspace. To provide a tangible reference and starting point in conversation participants were asked to bring an artifact with them (a project they have made). The third interview sought to understand the meaning of the participant's involvement in the makerspaces. To encourage reflection, participants were asked to draw a timeline of their making experiences throughout their life leading up to and including their experiences in the university makerspace. The modified single targeted interview protocol is rooted in the findings and themes of prior work [7] (that emerged from the three series) and also asked participants to draw a timeline of their experiences in making. This modified interview enabled us to obtain a sample size more appropriate for quantitative engineering design research. The semi-structured interview protocol is in Appendix A and the questions (for both interviews) centered around the themes of life history, details of experience, and meaning.

Of the 19 participants who participated in this study: 5 men and 5 women were from Big City U and 5 men and 4 women were from Comprehensive U. We sought out students who were highly engaged in the makerspace based on their potential to provide the most insight into learning in makerspaces. To do this snowball sampling was used, connecting potential participants via current participants to the interviewer. The interviewers utilized the makerspace Facebook page, word of mouth, and mutual connections to recruit participants. With the participant's consent, each interview was audio recorded, then uploaded to a computer and transcribed. The interviewer then edited the transcription to remove any superfluous banter, edit any phrases the transcriber didn't catch, and de-identify the participant/ remove any confidential information. In total, over 1000 pages of singe spaced interview transcriptions were produced and analyzed in this study.

Four out of five interviewers were from Big City U. Two were White men mechanical engineering graduate students, one was a White woman mechanical engineering graduate student, and one a White woman undergraduate mechanical engineering student. One interviewer, a White woman graduate student in communication studies, conducted interviews at Comprehensive U. All five interviewers had immersed themselves in the Learning through Making Typology and interview protocol prior to conducting interviews and were thoroughly trained by a qualitative faculty researcher in the methods. More details about each interviewer can be found in Figure 1.

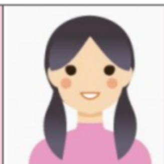
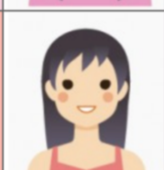
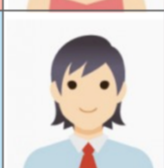
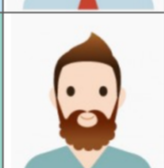
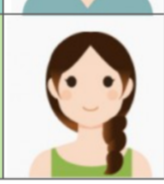
INTERVIEWER A		BIG CITY U	White woman Graduate mechanical engineering student	Interviewed 4 Women
INTERVIEWER B		BIG CITY U	White woman Undergraduate mechanical engineering student	Interviewed 2 Men
INTERVIEWER C		BIG CITY U	White man Graduate mechanical engineering student	Interviewed 1 Woman
INTERVIEWER D		BIG CITY U	White man Graduate mechanical engineering student	Interviewed 3 Men
INTERVIEWER E		COMPREHENSIVE U	White woman Graduate communication studies student	Interviewed 5 Men & 4 Women

Figure 1: Interviewer Break Down

3.2 Data Analysis

To manage the large volume of data produced, NVivo qualitative data management software was used. Three researchers participated in the analysis: an interviewer, an undergraduate researcher (UGR) and a qualitative faculty researcher. The qualitative researcher trained both the interviewer and UGR on the qualitative methods and analysis used in this study extensively over the course of several months. After immersing themselves in the data and the Learning through Making Typology, the interviewer and UGR began coding the same interviews until they reached satisfactory coding agreement. Using Miles and Huberman's [82] methods for assessing inter-rater reliability, an inter-rater reliability of 83.7% was achieved on 95% of the codes (including all categories of the typology) in the first four interview transcripts (making up ~12% of the data set). Any coding discrepancies in these four interviews was reconciled between the interviewer and UGR. Miles and Huberman assert that a baseline of 80% coding agreement on 95% of the codes is the benchmark for acceptable levels of agreement.

The interviewer and UGR coded the data using the Learning through Making Typology. Interviews were coded using the previously developed Learning through Making Typology as a basis [7]. One new code was added to the typology, but no new primary categories of the typology emerged. Under Content Knowledge and Skills, a sub-category Components was added. It is defined as the "discussion on a process, technique, or system used to carry out a task within a domain." Components was referenced when a participant discussed specific knowledge relating to common "mechanisms" in a field, like discovering of or differentiating between commonly used components in a domain that expands their design knowledge. For example, gears, bearings, specific operations in code, or electrical components. After reliability was established, the interviewer and UGR divvied up the remainder of the transcriptions to be qualitatively analyzed and added to the shared NVivo file. Once all of the interviews had been coded in NVivo, chi square analyses were used to quantitatively determine the significance of the findings and answer our research questions. Each time a primary category was coded (referenced) counted as an observed occurrence. To ensure reference count was an accurate reflection of occurrence, the interviewer re-unitized all of the transcriptions the UGR analyzed in NVivo.

CHAPTER 4. FINDINGS

4.1 Comparison of Learning Outcomes at Big City U & Comprehensive U's Makerspaces

Chi square analyses were used to determine the significance of differences between design competencies and learning types differ across learning communities. Observed values were calculated as the total reference count of each major learning typology category for each university respectively. Reference count was selected over word count coded since each reference captures a participant's train of thought. Further, the interviewer re-unitized the interviews coded by the UGR to ensure reference count is an accurate representation of occurrence. Table 2 shows the observed values for each university and typology category, as well as the results of the analysis. To answer the first part of the research question an overall chi square analysis was conducted on the learning typology across Big City U and Comprehensive U. Overall, Big City U and Comprehensive U do differ significantly in regard to design competencies and learning types in an academic makerspace, $\chi 2= 18.3$ (DOF=5, N=2508, p=0.003).

To investigate where these differences are coming from, individual chi square analyses were conducted on each category of the typology (i.e., Learning by Doing, Learning from Others, etc.). The observed and expected values are the same as prior and the critical chi square value is 3.841 for 1 DOF and a significance level of 0.05. The Universities differ significantly in Learning by Doing, Learning by Others, and Self-Awareness. The remaining categories are below the threshold of significance. Using the normalized reference count, it is found:

- Learning by Doing is referenced 17.6% more at Big City U
- Learning by Others is referenced 25% more at Comprehensive U
- Self-Awareness is referenced 22.2% more at Comprehensive U

Table 2: University Comparison Data

	BIG CITY U	COMPREHENSIVE U	X2	P-VALUES	ROW TOTAL
LEARNING BY DOING	200*	264*	4.12*	0.04*	464
LEARNING BY OTHERS	153*	309*	5.69*	0.02*	462
CONTENT KNOWLEDGE AND SKILLS	162	248	0.17	0.68	410
CULTURAL KNOWLEDGE	225	326	1.25	0.26	551
INGENUITY	48	54	3.14	0.08	102
SELF-AWARENESS	178*	341*	3.90*	0.048*	519
COLUMN TOTAL	966+	1542+	18.3+	0.003+	2508

Although Big City U and Comprehensive U are two very different makerspaces with much different engineering curricula, overall, they have many similarities. The major discrepancy between each is the modes of learning. At Big City U Learning by Doing is reported higher whereas Comprehensive U Learning by Others is higher.

Big City U has a well-known culture of being competitive. One participant noted:

> *"I think it's almost more like I really dislike having to feel like I'm on my guard or I need to defend myself, so I think if for some reason I needed to use the [makerspace], that would, I guess, just be my expectation of how it would go is that I needed to defend my qualifications or my knowledge."*

Competitive goals have been linked to ineffective interactions and weakened relationships amongst colleagues [83]. The lack of Learning through Others may be a product of the competitive academic environment. Another reason for the differences may be that Comprehensive U has a hand-on, project focused engineering curriculum as well as a much smaller program. Students are engaged in many team, making-centered projects throughout their education, and get to know nearly every student in the program, as well as the faculty. A participant at Comprehensive U noted:

> *"You're quite literally thrown onto project on day one of your time here as an engineering student. Literally on the first day of class, we were assigned a project with our leaders from the leadership program."*

The engineering program at Comprehensive U is a community in itself, whereas the makerspace at Big City U is a community found within a much larger program. Having such a tight knit community at Comprehensive U may be facilitating collaborative learning.

Comprehensive U participants were also found to have heightened Self-Awareness. For example, a student at Comprehensive U said:

> *"I'm not a total extrovert now, but I've definitely come more out of my shell and that's because of Dr. Y being like, "You're gonna do this thing for me." And I'm just like, "Well I don't have much of a choice now do I." <laughter> Like the presentation I gave yesterday, I got the assignment to do it on Tuesday at 4 o'clock. I was like, 'Okay!'"*

Self-Awareness was referenced when a participant displayed an intrapersonal understanding of their growth, attitude, motivation, and character. Self-awareness has been linked to increased confidence and adaptability to various challenges [84]. By becoming self-aware of their learning practices, students grow as thinkers. Students can develop self-awareness through reflective practices and inquiry, encouraging students to question their own learning, justify their methods, and take on new learning methods [84]. Comprehensive U's engineering program encourages this through pedagogical tools such as ePortfolios, learning records for course assessment, and student-agency in teaming and project selection.

It is important to note that everyone interviewed at Big City U is a self-identified maker, whereas at Comprehensive U every student is inherently a maker by nature of the engineering program. Integrating the makerspace into the curriculum may still be important even though the learning occurring at each University seen has many similarities. There is significant learning happening in these spaces and finding ways to bring students into the makerspaces and keeping them involved matters all the same.

4.2 Gendered Learning Outcomes in Makerspaces

To determine the significance of differences between men and women's design competencies and learning types a chi square analysis was also used. To eliminate any variables that may affect the results data from Big City U and Comprehensive U were analyzed separately. From Big City U, 10 interviews were utilized in this analysis from 5 women and 5 men (totalling 117 and 189 pages of single spaced transcriptions for women and men at Big City U respectively). To answer the first part of the research question an overall chi square analysis was used to see if there is significant difference between men and women participants for the Learning through Making Typology. Observed and expected values were calculated in the same manner as prior. Table 3 shows the observed data (based on reference count) from Big City U and the results of the analysis. Overall, men and women do differ significantly in regard to design competencies and learning types in an academic makerspace at Big City U, $\chi 2= 40.5$ (DOF=5, N=966, $p<0.00001$).

Table 3: Big City U Data

	WOMEN	MEN	X2	P-VALUES	ROW TOTAL
LEARNING BY DOING	81	119	2.6	0.11	200
LEARNING BY OTHERS	50	103	0.40	0.53	153
CONTENT KNOWLEDGE AND SKILLS	33*	129*	15.4*	0.00009*	162
CULTURAL KNOWLEDGE	98*	127*	7.1*	0.008*	225
INGENUITY	5*	43*	12.8*	0.0003*	48
SELF-AWARENESS	72	106	2.2	0.14	178
COLUMN TOTAL	339+	627+	40.5+	<.00001+	966

To better understand how men and women differ chi square analyses were conducted on the individual categories of the learning typology (i.e., Learning by Doing, Learning from Others, etc.). Men and women at Big City U differ in Content Knowledge and Skills the most significantly, followed by Ingenuity and Cultural Knowledge. The remaining categories are below the threshold of statistical significance. Content Knowledge and Skills is referenced **110% more for men** than women. Additionally,

Ingenuity is coded 360% more for men than women and **Cultural Knowledge is coded 45% more for women** than men.

The same process was repeated to analyze the data at Comprehensive U. In total, 24 interviews were utilized from 4 women and 5 men (totaling 309 and 429 pages of single spaced transcriptions for women and men at Comprehensive U respectively). Table 4 shows the observed data from Comprehensive U and the results of the chi square analysis. The total observed chi square for the learning typology was 27.6 (greater than the critical 11.07) proving there is a significant difference between men and women's design competencies and learning types in the makerspaces at Comprehensive U. To further decompose these discrepancies, individual chi square analyses were run for each category of the learning typology. Men and women at Comprehensive U differ in Content Knowledge and Skills the greatest followed by Cultural Knowledge. The remaining categories are below the threshold of significance. At Comprehensive U, **Content Knowledge is coded 90% more for men** than women and **Cultural Knowledge was coded 31.6% more for women** than men.

Table 4: Comprehensive U Data

	WOMEN	MEN	X2	P-VALUES	ROW TOTAL
LEARNING BY DOING	78	186	1.88	0.17	264
LEARNING BY OTHERS	118	191	3.01	0.08	309
CONTENT KNOWLEDGE AND SKILLS	53*	195*	16.4*	0.00005*	248
CULTURAL KNOWLEDGE	130*	196*	5.9*	0.015*	326
INGENUITY	19	35	0.07	0.79	54
SELF-AWARENESS	119	222	0.29	0.59	341
COLUMN TOTAL	517+	1025+	27.6+	0.00004	1542

Men at Big City U are coded significantly more than women for Ingenuity, though this phenomenon is not seen at Comprehensive U. Ingenuity is the least referenced category of the learning typology by far across all demographics. The large discrepancy could be due to the very small sample size of references.

One of the most striking features of the analysis is the discrepancy in Content Knowledge frequency across genders. Both Universities, though much different institutions, reflect the same pattern of men being coded for Content Knowledge much more frequently than women. This does not necessarily mean men have more knowledge than women – it may be that they just talk about their knowledge more in an interview setting. This could be a performance of masculinity. Gender research in psychology has shown while women use communication as a means to develop relationships, men use it to assert social dominance [85, 86]. Men are more likely to offer solutions to problems and avoid discussing interpersonal problems [87, 88]. Our data may be a reflection of this: men participants focused on what technical topics they have learned as a tangible answer to what they have added to their "toolbox" from their involvement in the makerspace. As well as, they may be sharing their wealth of knowledge as a means to assert their dominance as a bright maker. While on the other hand, women have focused more on their interpersonal skills developed from navigating the makerspace, particularly as a minority in the space.

Though our results align with feminine and masculine conversation styles, that may not actually be what is occurring. Although popular culture and media presume opposing conversation styles for men and women, actual research does not support such claims [89-94]. Race, ethnicity, social class, national origin, and language have far more influence on conversation style than gender [94-96]. We cannot attribute the wide discrepancy in content knowledge for men and women solely to gender.

Taking a closer look at our interview data, benevolent sexism occurring in our makerspaces became clear. All 5 women participants at Big City U and 2 women at Comprehensive U spoke of the assumed gender roles in these spaces, following a similar notion of men doing the hands-on work while women let them take over.

> *"Do you think the women are having a hard time overcoming those barriers to confidence, or that they are just behaving in ways that are like, culturally gendered expectations? [discussing culture of the machine shop]*
>
> *My dad notices sometimes when I talk to guys my voice gets higher and you act kind of dumber; at least, sometimes I do. Talking to a guy I think is cute, I'll act a little dumber, and my dad calls me out on it because he's like, "What are you doing?" I think that's true for a lot of females. I think they want the whole prince aspect where*

they like, rescue the girl in a way. The girls want the guys to do it for them and the guys want to help because they're men."

Though many of our participants observed these gendered behaviors, none aligned with such. The women participants in this study very clearly didn't want special treatment – in fact, often they found this behavior offensive and irritating.

"Mostly during the bike project that's happened, especially working with all guys. I'd be working on something and they'd come over and try and take over. I'd get mad. I hate that. Guys don't do it to guys, though."

Judith Lorber [97] asserts gender as process, stratification, and structure where "individuals learn what is expected, see what is expected, act and react in expected ways, and thus simultaneously construct and maintain the gender order." Gendered expectations and norms are enforced and reinforced in everyday interactions asserting men as the dominant gender and women as subordinate. These gender roles are transferring to the makerspaces as men participants taking lead in hands-on work and taking over women participants tasks in a manner that is perceived on the surface as being helpful or nice. While the intentions aren't harmful, these behaviors can be negatively impacting our women makers and furthering the divide in Content Knowledge between genders.

Further, throughout the interviews we found the makerspaces are breeding a culture of competition. Women participants spoke of their men counterparts flaunting their projects and technical jargon as a means to assert their place in the makerspace.

"You have to go in and it's like you have to throw some jargon at them [male makerspace workers] so that they're like, "Oh, oh, okay. Okay, you're in the club," or whatever."

Foor et al. [98] found in a study of an engineering design competition team "the team culture restricts a declared-open educational community to only those students who have the freedom and assertiveness to insert themselves into the organization and reject other aspects of student life." The exclusive competition culture seen in engineering environments may be restricting women makers from participating in our makerspaces.

The fact remains that there is learning occurring in these makerspaces for **all** participants. Significant barriers to entry for women exist [7, 8, 71]. Through these spaces' women gain support, respect, and find a sense of identity as a maker. It is important in developing an inclusive, welcoming makerspace to create making-related catalyst opportunities to bring women into the space and provide consistent affirmations to keep them in the space [71].

To assist in breaking down the large volume of data, a bar chart (Figure 2) organizes the frequency of reference for each category of the learning typology against each demographic: women at Big City U, men at Big City U, women at Comprehensive U, and men at Comprehensive U.

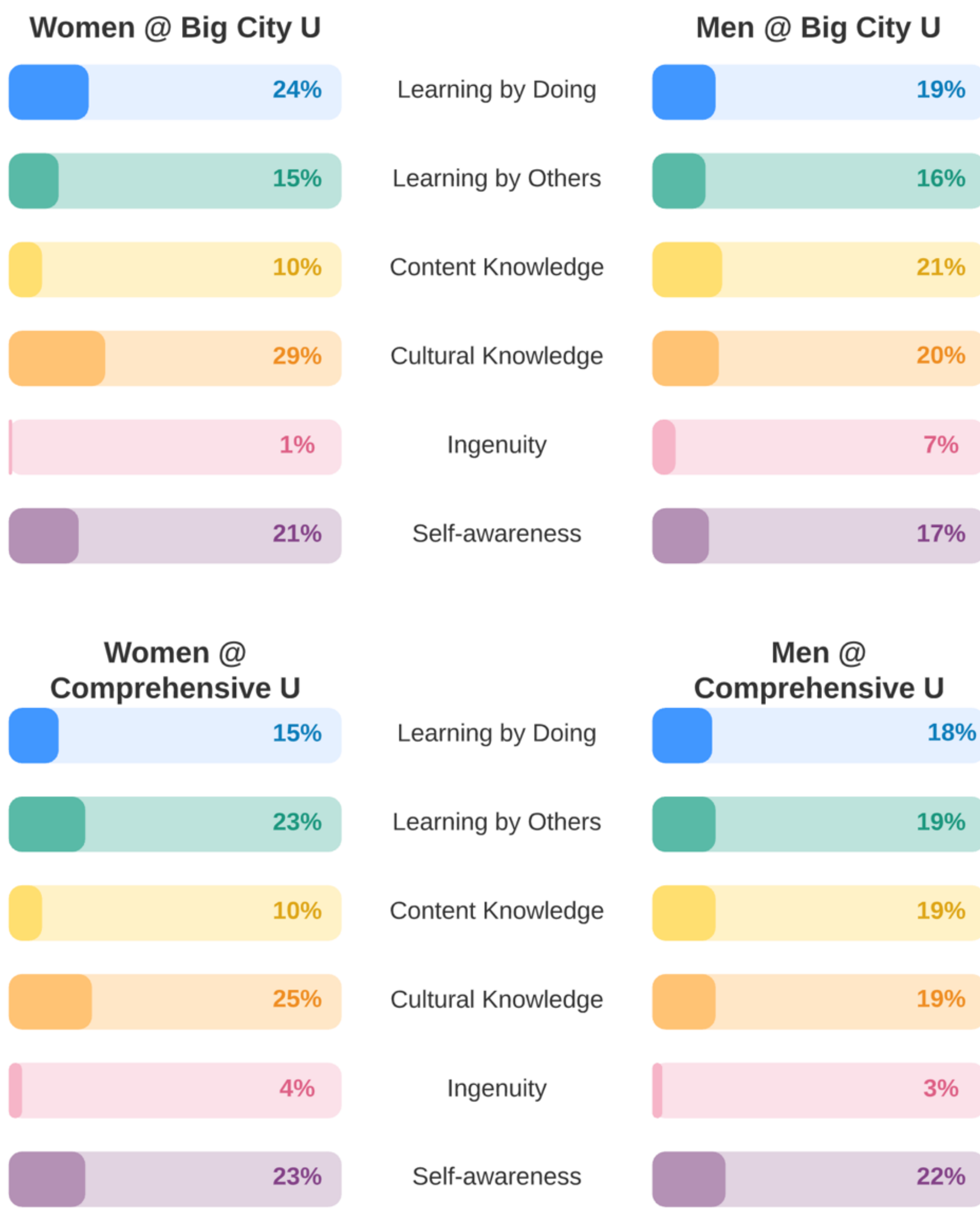


Figure 2: Bar Chart of Frequency of Reference

4.3 Learning in Virtual Maker Communities

4.3.1 Online Learning Model

The in-depth phenomenological interview approach provides a deep look into the students learning in and out of makerspaces. As the interviewers were analyzing the data, the significance of online learning was apparent. Nearly three quarters (73%) of students interviewed mentioned online learning—even though the interviewer never prompted the subject. Through multiple cycles of coding, the learning model shown in Figure 3 was developed. The model aims to show how students are learning online and how this online learning supplements their in-person making.

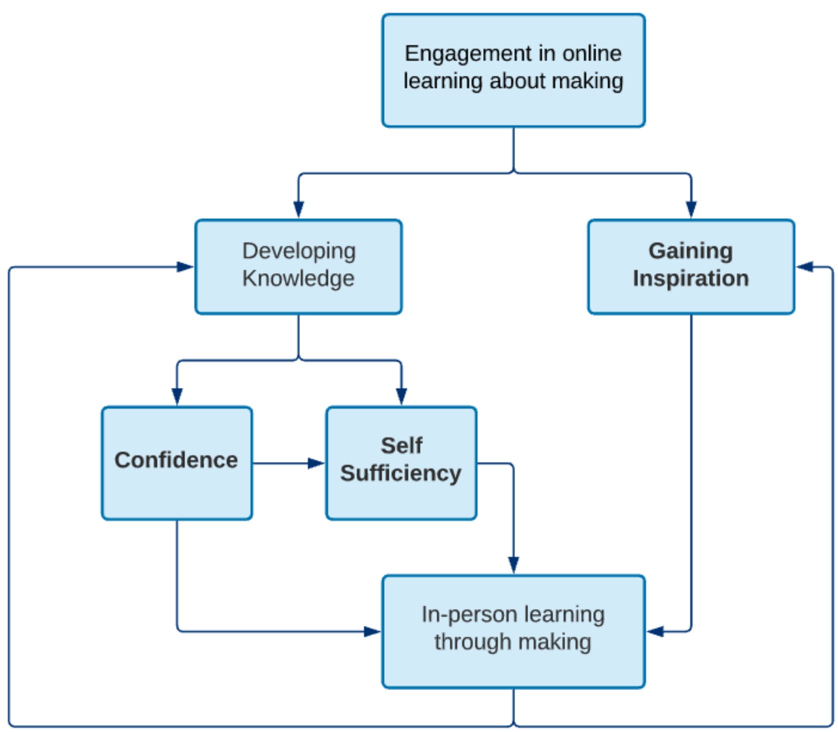


Figure 3: Online Learning Model for Makers

The online learning cycle is experienced as "endless" to students. Makers discover information online, whether they passively came across it or actively sought it out, and then apply that new knowledge in their making. Then when approaching the next making project they repeat the cycle – returning to online sources as a means of learning.

There are two main pathways in the model: (1) developing knowledge, and (2) gaining inspiration. As makers come across information online, they develop new skills and knowledge to add to their toolbox or find inspiration for a project—sometimes both. Through being able to develop maker-related skills virtually, students are able to develop confidence to apply that knowledge through physical making. Further, by having the confidence to try new tools, as well as having expert information at their fingertips, online learning appears to be fostering the development of self-sufficient makers. The following sub-sections describe the identified three important features of the model that were key to student experiences: confidence, self-sufficiency, and inspiration.

4.3.1.1 Confidence

Confidence is described by students as simply being comfortable to walk into the makerspace. For example, Liam, a Junior at Comprehensive U, recounts his first experience welding. Prior to first stepping foot in the makerspace, he watched videos to understand what to expect, common pitfalls, and the tips and tricks to a good weld. When he went to do his welding training, he impressed the instructor—his welds were good the first try. Liam recommends for any future makers who want to pursue welding to follow a similar process as him:

I would tell them before entering the makerspace to watch as many YouTube videos on how to weld, different types of welding, the different nuances of welding. Like the feed speed, what kind of wire you use, how to weld with different materials because there's just so much information you can learn that way and even if you don't absorb all of it, even if you just have it playing in the background, just kind of being vaguely familiar with it even, for me at least, inspires a lot confidence, especially with something that can be as daunting as welding.

The significance of online learning for Liam's weld experience is clear. Through what appears to be a passive experience of watching a video about welding, the feeling of intimidation related welding is diminished. Thus, through visiting online platforms such as YouTube, students are able to know what to expect in the makerspace—without ever stepping foot in one. The sense of familiarity this brings can be profound for maker's confidence.

4.3.1.2 Self-Sufficiency

Self-sufficiency was described by students as being able to teach yourself the fundamentals, at the very least, of what you're working on. Having instant access to expert knowledge is producing more well-versed, self-sufficient makers. For example, students working on a project using an unfamiliar material are not limited to seeking assistance during a materials professor's office hours; they can just search for the information online. In fact, oftentimes it's expected for students to take the first step of doing own research before seeking out help from others. Through virtual communities and online resources, makers reap some of the similar benefits that one experiences through collaboration within the contexts of their independent work.

Confidence was also an important precursor to self-sufficiency in students' accounts. In the prior example, Liam was not required to weld himself; he could have instead dropped off his parts at the machine shop to have the weld completed by the shop. He had an interest in welding, though, and he built confidence through watching YouTube videos before taking the step of learning to weld himself. This experience developed his skillset and helped him to become a more independent maker.

Will, an upperclassman at Big City U, spoke of what he coined "creative confidence." The belief that he could complete a project independently even if he never done it before.

> *I'm going to go to look it up and watch some YouTube videos or something, and figure out how to do that other part, because I know I can do this. I know I can do 75%, 80% of that project without doing anything else, I'll look up the rest.*

Will is confident that through his past experiences, even if not directly applicable, and the endless online resources, he can figure just about anything out by himself. Like Liam, Will's experience and confidence was an important pathway toward self-sufficiency as a maker.

4.3.1.3 Inspiration

Beyond gaining new skills and knowledge, the internet was described as a phenomenal resource to find inspiration to apply to one's own making. Students interviewed used words like effective, faster, simpler, and more viable to describe how the internet inspired their making. Whether it was watching their favorite makers new YouTube video and wanting to recreate the project themselves, or idea generating for a class project, students saw online inspiration as an important pathway to making.

Thomas, a Junior at Comprehensive U, asked his professor for help in improving his bike design and was suggested to use Google images. They pulled up the search engine on the projector and parsed through images.

> *If you don't know specifically what you're searching for and you just look up on Google Images something that's related to it, then you might find something that helps with it. In this instance, we weren't looking for a redesign of that part specifically, but once we saw the picture of a bike that somebody had already made, then we knew that could be used for this.*

Taking directive from the image found, Thomas was able to implement the redesign in his own work, improving upon an aspect of his design he had no intention of changing.

4.3.2 Virtual Making Communities as Sites of Collaborative & Contextualized Learning

Prior research has demonstrated the link between experience and confidence [99]. Though online learning is not a physical, “hands-on” learning experience, it is still an interactive and engaging learning experience. From the confidence developed through online learning, students in this study stepped out of their comfort zone and developed new skills within the physical makerspace. They were able to apply expert knowledge found online in their own work, extending their independent capabilities drastically. This suggests blending online, out-of-class learning with more active learning activities in the classroom (e.g., flipped classroom), as opposed to traditional lecturing, is an approach our students intuitively apply to their own personal making-focused learning.

To be sure, using the internet as a source of inspiration is nothing new. Take for example Pinterest, a popular social media site used to "discover recipes, home ideas, style, and other ideas to try." People are using online platforms to assist in all aspects of life, including making. With the abundance of projects posted online in making communities, it's an effective way for makers to find ideas and inspiration to apply to their own work. Using a search engine, such as Google, has proven to assist people in memory retrieval that may help improve their ideas [100]. Indeed, engineering educators can leverage student interest in such social media platforms toward creating a more connected classroom, enabling students to share ideas, questions, and feedback.

Given the relatively recent growth of the maker movement, coupled with relatively quick build-up of campus makerspaces, occurring alongside the growth of ubiquitous computing, it is not surprising that our digital-native students engaging in our makerspaces are turning to social-media and other community-based making websites and forums to learn about materials, electronics, tools and tooling as well as to find inspiration, methods, and procedures. Websites such as TinkerCAD and 123Design coupled with early desktop 3D printer such as the MakerBot brought digital design, modeling, and printing to the non-expert, while sites such as Thingiverse showed the non-expert what was possible. Beyond these simple making solutions, the internet provides extensive making and manufacturing knowledge and inspiration with instruction and projects for the laser cutter, vinyl cutter, lathe, CNC, waterjet – just to name a few. Everything from how to videos, pictures of projects, and project plans are available. Many of our students have grown up interfacing with this software and hardware using their laptops, tablets, and phones at their homes, in their primary and secondary schools, and now at their Universities.

And now, more than ever given the Covid-19 pandemic, there is urgency to understand how our students learn online—both independently as well as coupled to in-person, virtual, and hybrid communities. Our rapid shift from a traditional face-to-face course delivery system on most residential campuses to online instruction has left many grappling at solutions that accommodate our students, encourage engagement, and facilitate learning. And while it is unknown whether we will be able to return to "business as usual" in terms of in-person learning, findings such as ours show that there is promise for the effectiveness of e-learning even in making centered engineering programs and allow us to ask "should we return to business as usual." Liam described his experience learning online:

> *It's that informal background and theoretical knowledge, which is I think very similar to the knowledge you get in a classroom; I think it is paramount to really all education that you get that contextualized experience and that actual application of it. Cause they can teach me something in Mechanics and Materials and I'll take their word for it but it's not particularly intuitive right? The Young's modulus of steel, I get what that means, I get what it represents, but actually seeing it in, in action knowing that if you weld too fast on cast iron it will crack because of that. Getting that application is really useful, solidifies the information you learn and contextualizes it.*

Connecting theoretical concepts with application: for Liam it is through YouTube, for the authors on this manuscript, it was through choreographed laboratory experiences. We ask, does it matter which channel is employed? What seems clear is that contextualized learning, such watching a YouTube video, facilitates both individual and collaborative processes of learning and knowledge building [101]. This promotes a rich, deeper understanding for students, and we believe that these online channels should be integrated and celebrated as critical component of one's development into a professional and an engineer.

CHAPTER 5. CONCLUSIONS

The work in this thesis aims to provide insight into how learning compares across various making communities. Using the previously developed methodology and the Learning through Making Typology, which showcases the modes and products of learning in the makerspace, we are able to both qualitatively and quantitatively compare students learning outcomes. The learning typology is confirmed in these findings proving that it translates across genders and there is significant learning happening for all. Comprehensive U's engineering curriculum integrating the makerspace and focusing on learning by doing is encouraging students to learn from one another – enhancing collaboration, leadership skills, and communication. Every engineering student at Comprehensive U is inherently a maker by nature of their program, forcing students into the makerspaces and keeping them involved.

It is clear from our interviews and analysis that our makerspaces are influenced by the greater engineering and societal culture. Gendered expectations and norms exist in these spaces and the role of mentors and educators really matters to create a more equitable makerspace. The competitive framework instilled by our engineering programs sets up competitive spaces (the makerspaces are no exception to this) encouraging students' learning through this patriarchal competitive domain. Just as the structure and integration of the curriculum at Comprehensive U interrupts the types learning seen between each university (e.g. more collaboration and self-reflection can be taught/encouraged), there are interventions to be done that can disrupt the gendered masculine culture of these spaces. These could be simple changes such as video tutorials of each tool demonstrated in the local makerspace or a map of the space to make the makerspace more approachable. Student workers could go through training on micro-aggressions or anti-sexism. Even just having the conversation and bringing awareness to the benevolent sexism occurring in the makerspaces (revealed in this study) is a step in the right direction. From the Learning through Making Typology and the work of this study it is clear that there is significant learning happening in these makerspaces – it is so important to create an equitable and approachable environment to encourage students to participate and engage their makerspaces.

Key themes identified through analysis of ethnographic interviews are presented as well as our initial model illustrating how students use online learning to supplement in-person learning and making in makerspaces. In essence, for our engineering students, makerspaces facilitate a hybrid learning environment. We believe that this online learning model shows promise for transferability beyond making as well. In other words, whether it's looking for a recipe for dinner tonight or learning how to weld a bike—we suspect that the process may follow the model created (Figure 3).

While maker communities are often thought of as a physical space, in reality, they extend beyond the limitations of one's local means. Online platforms are supporting makers confidence, developing their skillset, and providing a way of sharing and exploring endless projects from makers around the world. These digital spaces are furthering the development of competent, inspired makers.

CHAPTER 6. FUTURE WORKS

This thesis presents a qualitative approach to comparing student learning outcomes in makerspaces. While this paper explores student learning at two unique universities, between genders, and online, there is much more work to be done. Future work exploring more universities and with a greater number of participants would provide clearer insight into the relationship between students' learning in the makerspace and curriculum structure. By increasing the number of participants of diverse backgrounds we can gain insight into other factors that may impact student learning such as race, sexual orientation, first generation college students, socioeconomic status, and much more.

Further, this study focused on the learning outcomes of makerspace involvement. But there are more areas to explore such as professional development and networking, design self-efficacy, and much more. Within the interview transcriptions already collected much of this can be explored. Our over 1000 pages of data are rich in themes beyond just learning such as social constructs, engineering culture, university culture, and so much more.

The Learning through Making Typology's transferability can be explored beyond just engineering. A comparison with students in industrial design/ the arts would provide insight into how gendered masculine makerspaces vs feminine makerspace (often referred to as studios) compares.

APPENDIX A. INTERVIEW PROTOCOLS

IN-DEPTH PHENMONOLOGICALLY BASED INTERVIEW JOTTINGS

Interview One

- Interest in how you got involved
- Before GT; Growing up, what was is like for you with creating or making things
- attracts you to this space or types of spaces
- inspires you to use the space
- elementary school
- High school
- Keeps you going
- Person who has influenced you
- Clubs, activities
- What did you do growing up, things you were involved in

Interview Two

- What you do
- What do you call what you do
- How do you go about making something
    - Walk me through the process
- Describe experiences you have
- Typical week, day
- Interaction with other students, faculty, staff --- daily, monthly, etc.
- What is it like for you to be involved in this space
    - In making
- Roles
- Rules
- How does using the space come about in a typical week
- Dynamic of class + leisure + anything else come into fruition in makerspace … in making
- For someone who has never been here, how would you characterize/talk about the space

Interview Three

- Timeline
- For someone who has never been here, how would you characterize it
- What do you call what you do here
    - Making, crafting
- Given what you have said about your experience before + now, how do you understand __ in your life
    - What sense does it make to you
- Where do you see yourself going in the future?
- How has this changed/shaped your life?
    - Role as student, learner
    - Types of skills
    - Way of thinking
    - Goals + how to achieve them
- Takeaways
- What in your life do you attribute to this space?
- Experiences = important, impactful
- Speak to what is like being female in these spaces
- Confidence
- Role of space/making in life?
- How do you see yourself (your role) in these spaces?

SINGLE, TARGETTED INTERVIEW PROTOCL

Thank you for agreeing to meet with me today. I have us scheduled for an hour together. Does that still work for you? I want to honor our time constraints today. If we reach the hour and you would like to expand on the questions more, I would compensate you for the additional time. Nevertheless, while I encourage you to elaborate on your answers to my questions, there may be times when I redirect, so that we may be sure to cover all the topics in the hour.

<go over IRB>

This meeting is focused on your making, design, and learning experiences as a woman involved in the makerspace.

So I want you to think of your experiences making and what you've learned throughout these experiences. I want you to imagine that you've had this toolbox and every time that you've learned something, you add it to your toolbox. And what I'm interested in is what is in this toolbox because of your involvement in the makerspace, so what it looked like before and what it looks like now.

In order to help you navigate the loads of things that you've done in your life, I want you to first start off with creating a timeline of your making experiences growing up to now.

Could you highlight the point for where you began your involvement in the makerspace at [University]?

Now, looking at this region for growing up to your involvement, what would you say was in your toolbox?

Now since your involvement, what has changed in your toolbox?

What has changed in regards to:

- Knowledge in course-related topics such as design, manufacturing, materials
- Ability to understand and navigate a specific culture or community
- Creativity
- Personal growth and your perspective on making
- Navigating your identity as a woman in the makerspace
- Communication skills
- Leadership skills

Has your way of thinking through a problem changed? Could you walk me through an example.

How would you characterize *how* you learn in the makerspace?

What are some of the things that you have learned how to make in the makerspace?

Overall, how has your experience in the makerspace impacted your life?

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